Human-Automation Integration Research

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Human-Automation Integration Research

Overview

- **Acronyms**
- **Goals and Objectives**
- **Deliverables**
- **Roadmap & Milestones**
- **Funding Plan**
- **Collaboration & Technology Transfer**
- **Facility Utilization**
- **Accomplishments**
- **Project Assessment**
- **Future Directions and Element Changes**
- **Summary**

Acronyms

- **AGIE** — **Air-Ground Integration Experiment**
- **AvSP** — **Aviation Safety Program**
- **CATS** — **Crew Activity Tracking System**
- **CBT** — **Computer-Based Training**
- **CFIT** — **Controlled Flight Into Terrain**
- **DAG** — **Distributed Air-Ground**
- **FAA** — **Federal Aviation Administration**
- **FGSHWG** — **Flight Guidance Systems Harmonization Working Group**
- **FMA** — **Flight Mode Annunciator**
- **GCP** — **Guidance Control Panel**
- **GT-CATS** — **Georgia Tech Crew Activity Tracking System**
- **HAIR** — **Human-Automation Integration Research**
- **ITS** — **Intelligent Tutoring System**
- **JSRA** — **Joint Sponsored Research Agreement**
- **LaRC** — **Langley Research Center**
- **MCP** — **Mode Control Panel**
- **MIT** — **Massachusetts Institute of Technology**
- **OFM** — **Operator Function Model**
- **OFMspert** — **Operator Function Model/Expert System**
- **RTCA** — **Radio Technical Committee for Aviation**
- **S/WE** — **Software Engineering**
- **SAE** — **Society of Automotive Engineers**
- **T-NASA** — **Taxiway Navigation and Situation Awareness**
- **UC** — **University of California**

AOS Base Program
Key Goals of Pillar One

Enhanced Safety

Increased Capacity

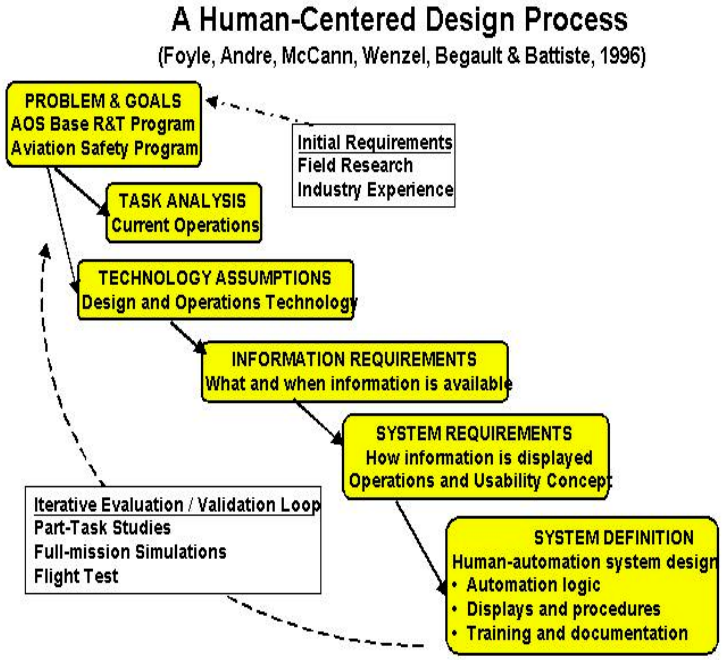
Access to Space

GOALS and OBJECTIVES

HAIR

Human-Automation Integration Research Goal

Enhance capability, improve safety, and reduce costs of automated aerospace operations.



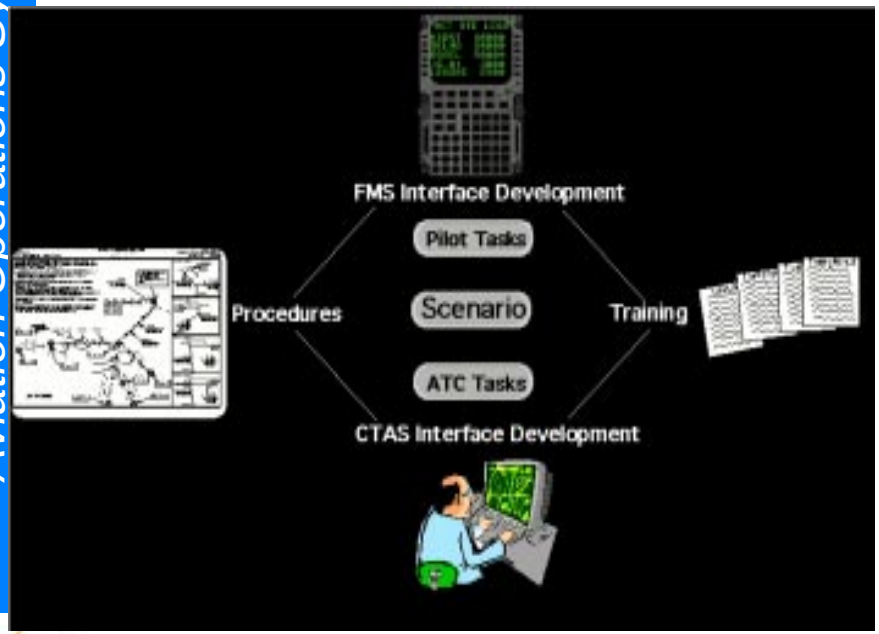
Objectives

With US industry and federal agencies:

- Eliminate mode error as a cause of accidents
- Demonstrate cost-effective training for automation
- Demonstrate human-centered design of displays and procedures
- Develop predictive task analysis methods
- Support FAA certification efforts

Progress

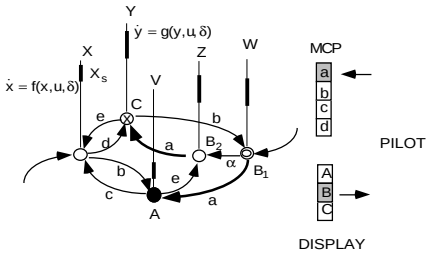
- Recognition of the problem (1980-85)
- Documentation of the problem (1985-)
- Weak solutions proposed (1990-)
- Single-point technologies (1985-)
- Hybrid control theory (1970-)
- Large-scale analyses (1990-)
- Industry-relevant demos (1995-)
- Certification issues addressed (1995-)



HAIR

CURRENT APPLICATION: HUMAN FACTORS OF MODE CONFUSION

FAILURE STATE	C
DISPLAY SHOWS	B
PILOT UNAWARE OF TRANSITION	α
SAME ACTION LEADS TO DIFF BEHAVIOR	
OBSERVABILITY THEORY FOR HYBRID SYSTEMS	



Challenges

- Integrated design synthesis
- Distributed systems
- Scale and heterogeneity
- Tool usability
- Rapid prototyping
- Cognitive modeling
- Display content modeling
- Validation

L3/L4 Sub-Elements

L3 Technical Focus: Modeling, Design, and Analysis

1.0 System Design and Analysis		
1.1 State Awareness and Prediction	1.2 Displays and Procedures	1.3 Human-Auto. Theory

L3 Technical Focus: Simulation and Validation

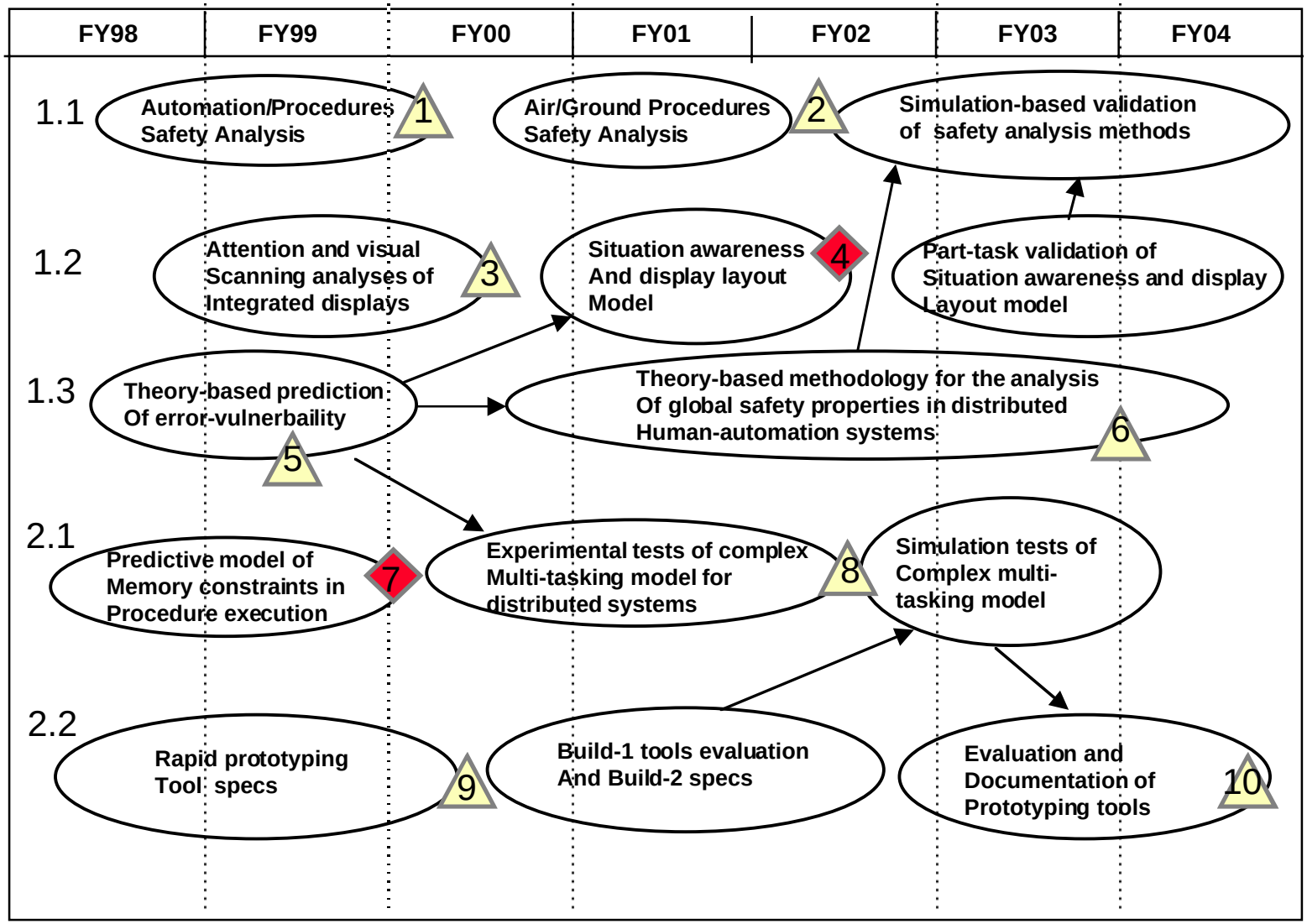
2.0 Human-Automation Reliability	
2.1 Supervisory Control Behavior	2.2 Prototyping for Evaluation of Automation

DELIVERABLES

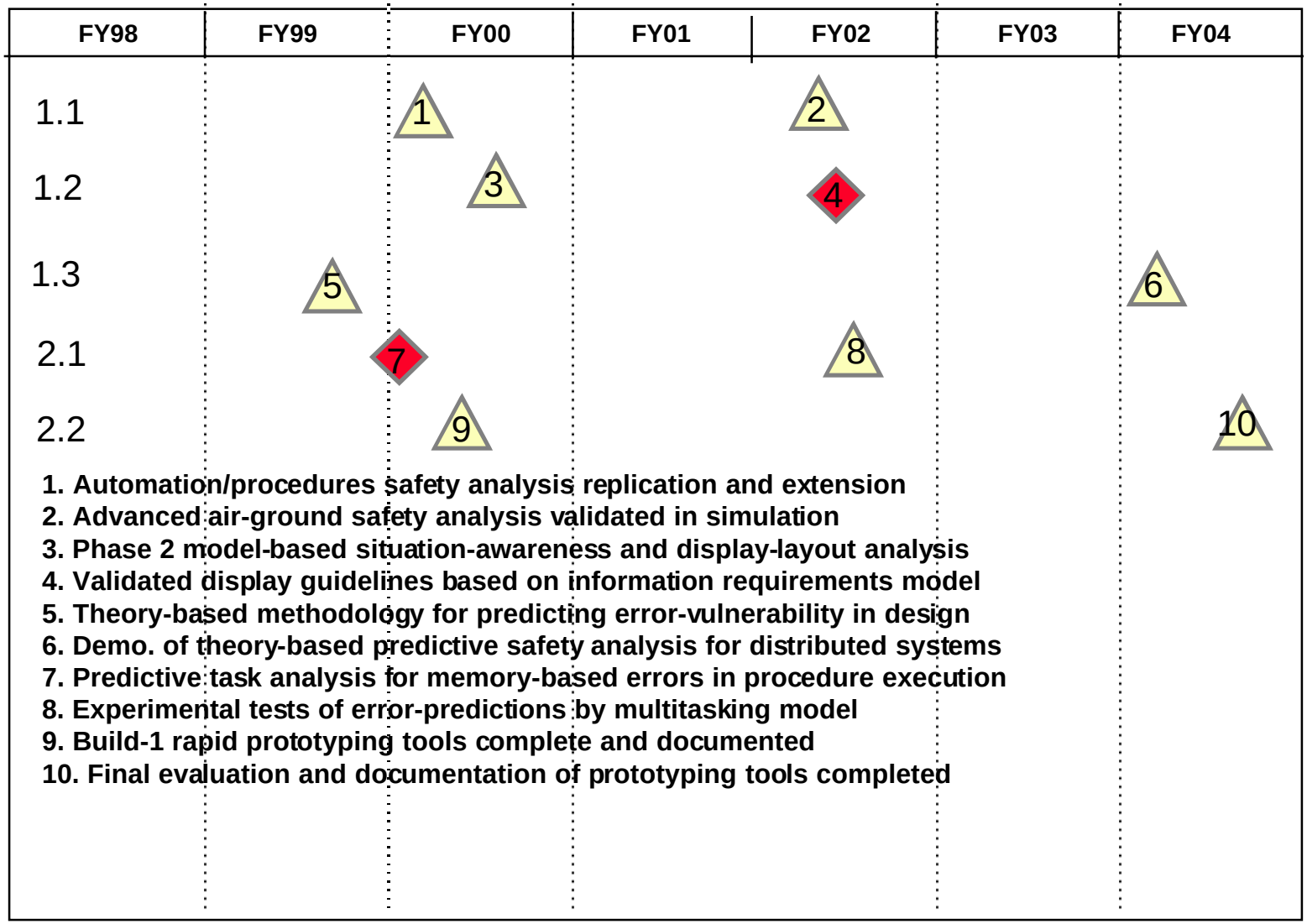
- Elimination of mode error as a cause of accidents (Safety & Capacity)
  - **Formal methods for human-automation design synthesis**
  - **Analysis of known automation-induced errors**
  - **Analysis of current generation flight control systems**
- Improved cost-effectiveness of training (Aviation Safety Program)
  - **Intelligent Tutoring Systems for Automation Training**
  - **Work in support of Aviation Safety Program Training Element**
- Demonstrate cost-effective design of displays and procedures (AvSP)
  - **Taxiway Navigation and Situational Awareness (T-NASA) base R&T, methodology, and lessons learned for human-centered design**
  - **Model-based methodology for procedure-execution modeling**
  - **Display modeling and cognitive walkthrough methodology**
- Predictive methods for automation safety analysis (AvSP)
  - **Systems for modeling expert supervisory control behavior**
  - **Conjoint analysis of systems, procedures, documentation, and human factors**
  - **Formal analysis of redesign concepts based on known errors**
  - **Predictive task analysis**
- Support FAA certification efforts
  - **Workshops and Conferences**
  - **FAA Flight Guidance Systems Harmonization Working Group support**
  - **Integrated Technology Demonstrations**

ROADMAP & MILESTONES

HAIR



MILESTONE KEY



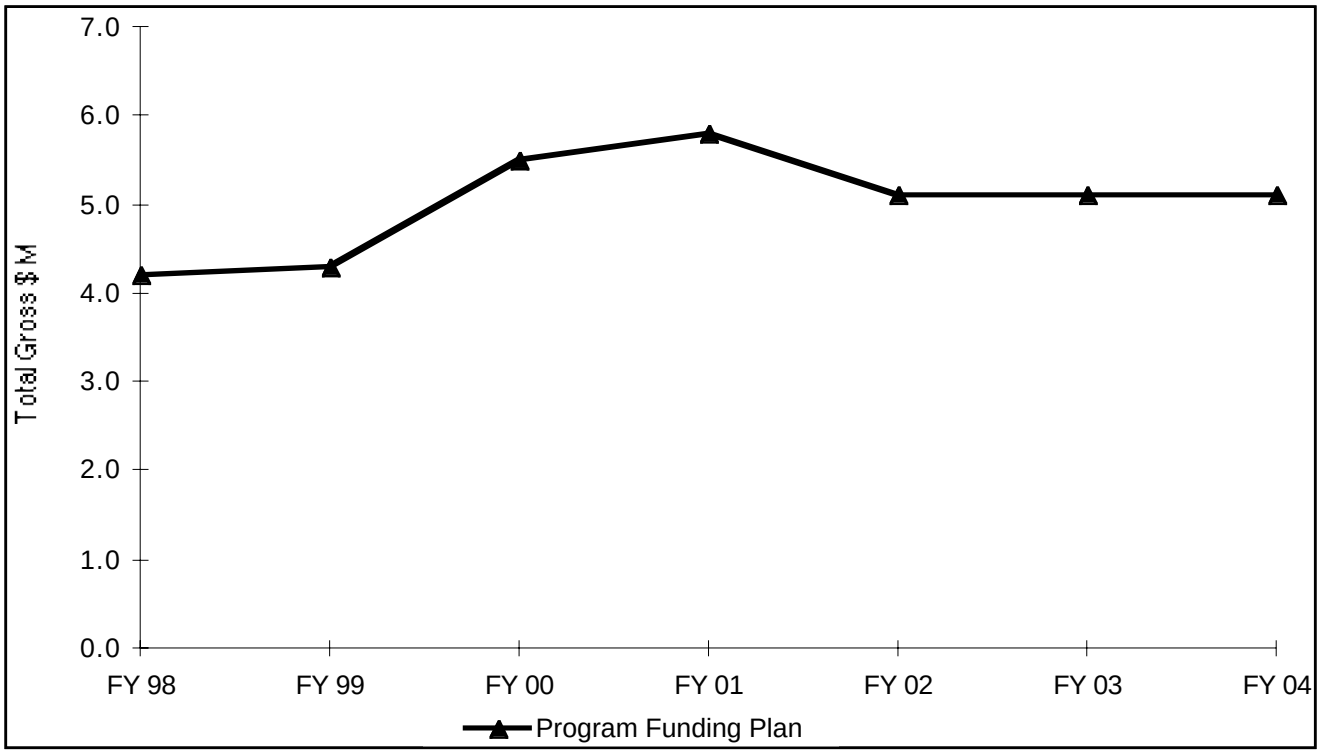
1. Automation/procedures safety analysis replication and extension
2. Advanced air-ground safety analysis validated in simulation
3. Phase 2 model-based situation-awareness and display-layout analysis
4. Validated display guidelines based on information requirements model
5. Theory-based methodology for predicting error-vulnerability in design
6. Demo. of theory-based predictive safety analysis for distributed systems
7. Predictive task analysis for memory-based errors in procedure execution
8. Experimental tests of error-predictions by multitasking model
9. Build-1 rapid prototyping tools complete and documented
10. Final evaluation and documentation of prototyping tools completed

Level 2 milestones

Level 1 milestones

PROGRAM FUNDING PLAN

Human/Automation Integration Research (HAIR)



Program Funding Plan	FY 98	FY 99	FY 00	FY 01	FY 02	FY 03	FY 04	Total
Net Totals	2.2	2.8	2.6	2.6	2.0	2.0	2.0	16.2
Program Support	2.0	1.5	2.9	3.2	3.1	3.1	3.1	18.9
Total (Gross)	4.2	4.3	5.5	5.8	5.1	5.1	5.1	35.1

Facility Utilization

- Boeing 737-X engineering simulator
- Honeywell engineering simulators
- McDonnell-Douglas MD-11 simulator
- Fed Ex training simulators
- Ames 747-400 simulator
- Ames Advanced Concepts Flight Simulator
- Human Performance Laboratory Part-Task Labs
- Ames Airspace Operations Lab
- Georgia Tech Part-Task and Intelligent Training Simulators

COLLABORATORS

University

- Georgia Tech
- San Jose State University
- MIT
- Stanford University
- UC Berkeley
- University of Illinois
- UC San Diego
- University of Colorado
- Northwestern University
- Technion
- Wayne State University
- Johns Hopkins
- University of West Florida
- University of Illinois - Chicago
- Ohio State University
- University of Miami (FL)

Industry/Government

- Honeywell
- Fed Ex
- United Airlines
- Continental Airlines
- US Airways
- FAA
- Boeing
- Volpe
- Battelle
- Monterey Technologies
- Raytheon
- Formal Methods Group (LaRC)
- SRI International
- Advanced S/WE Group (ARC)

TECHNOLOGY TRANSFER ACTIVITIES *HAIR*

Customers	Direct Partnership	Indirect Tech Transfer
S&E Community	University Research Collaborations	Publications/Presentations
Aerospace Community	Workshops	Aviation Safety Program (Training, Displays, Error)
	SAE, RTCA etc.	Capacity Programs (DAG) (Air-Ground Integration)
Airframe Manufacturers	Research Collaborations Workshops, Briefings	
Avionics Industry	Research Collaborations Workshops, Briefings	
Airline Operators	Research Collaborations Workshops, Briefings	
FAA	FAA-sponsored Research (datalink) Joint Research Activities (AGIE)	

MAJOR ACCOMPLISHMENTS (4/98 - 12/98)

HYBRID DYNAMIC SYSTEMS

CO-EXISTENCE OF DYNAMICS AND LOGIC

MULTIPLE, INTERACTING AGENTS

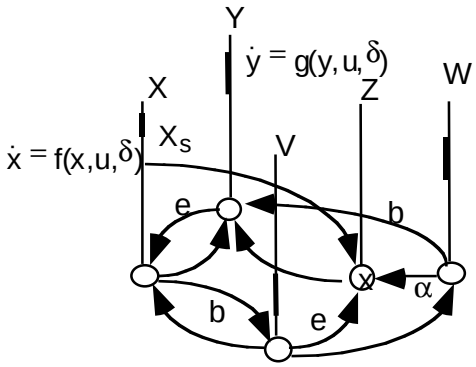
KEY ISSUES: SAFETY AND LIVENESS

MUST MERGE

DIFFERENTIAL GEOMETRY & AUTOMATIC CONTROL

&

FORMAL LOGIC & AUTOMATA



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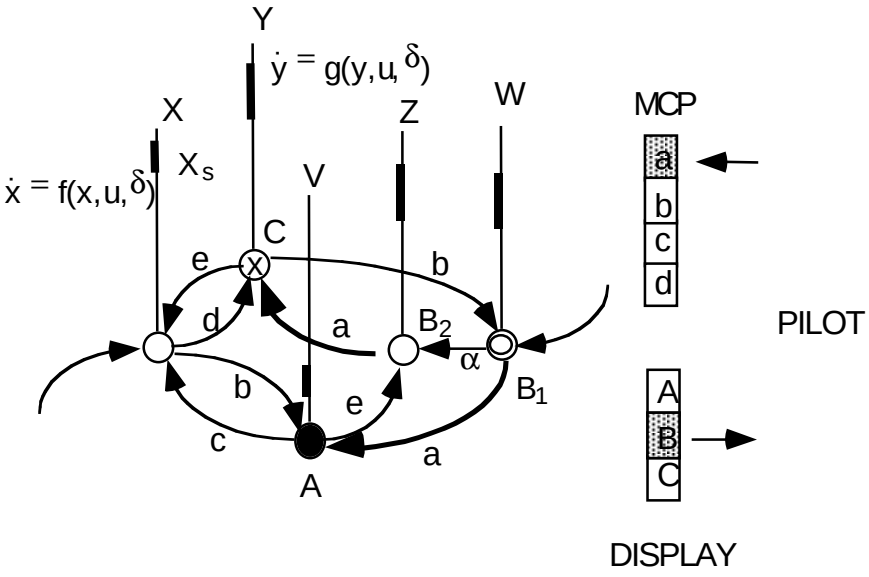
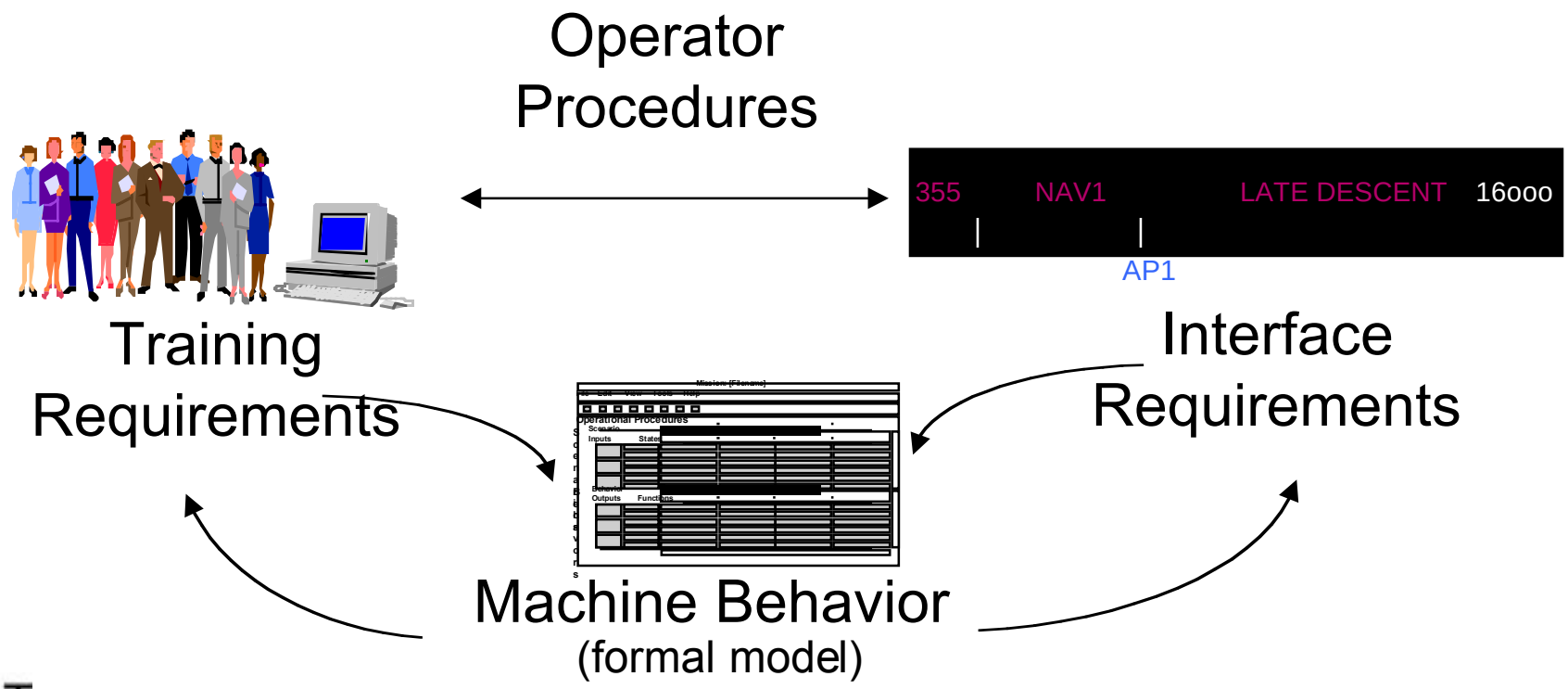


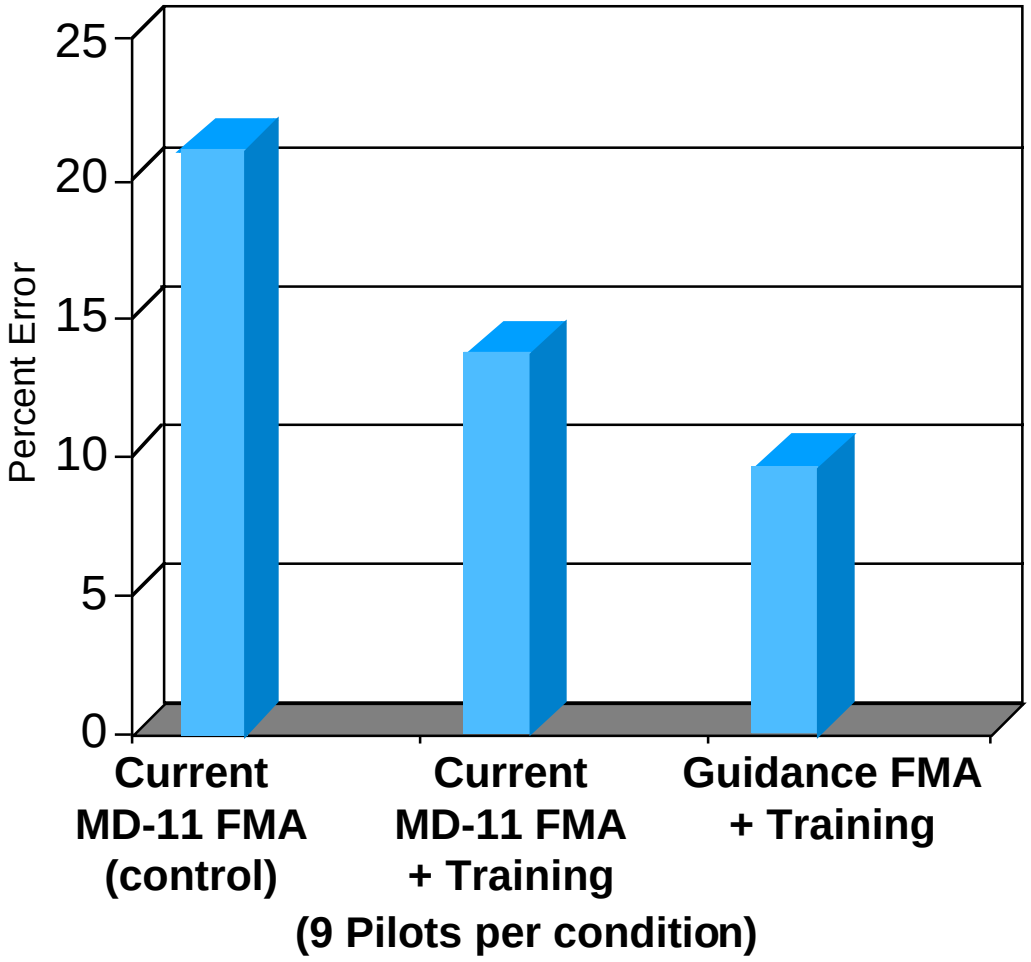
Operational Procedures Methodology

Improve pilot recognition and understanding of aircraft behavior in automated flight by designing a display & training package based on a model of the behavior of the avionics.



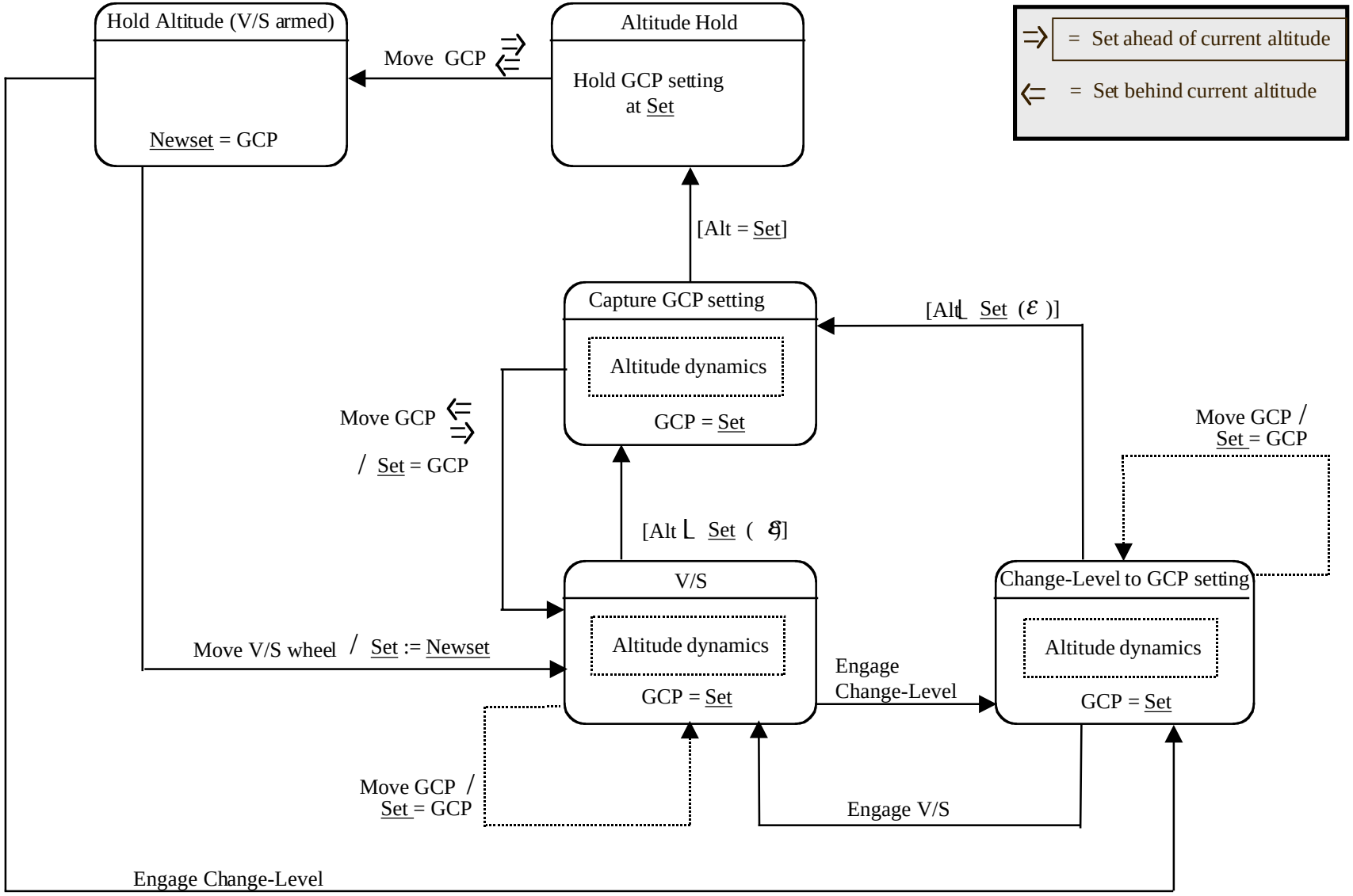
Results

Mode-Awareness Task: "Predict the next FMA."

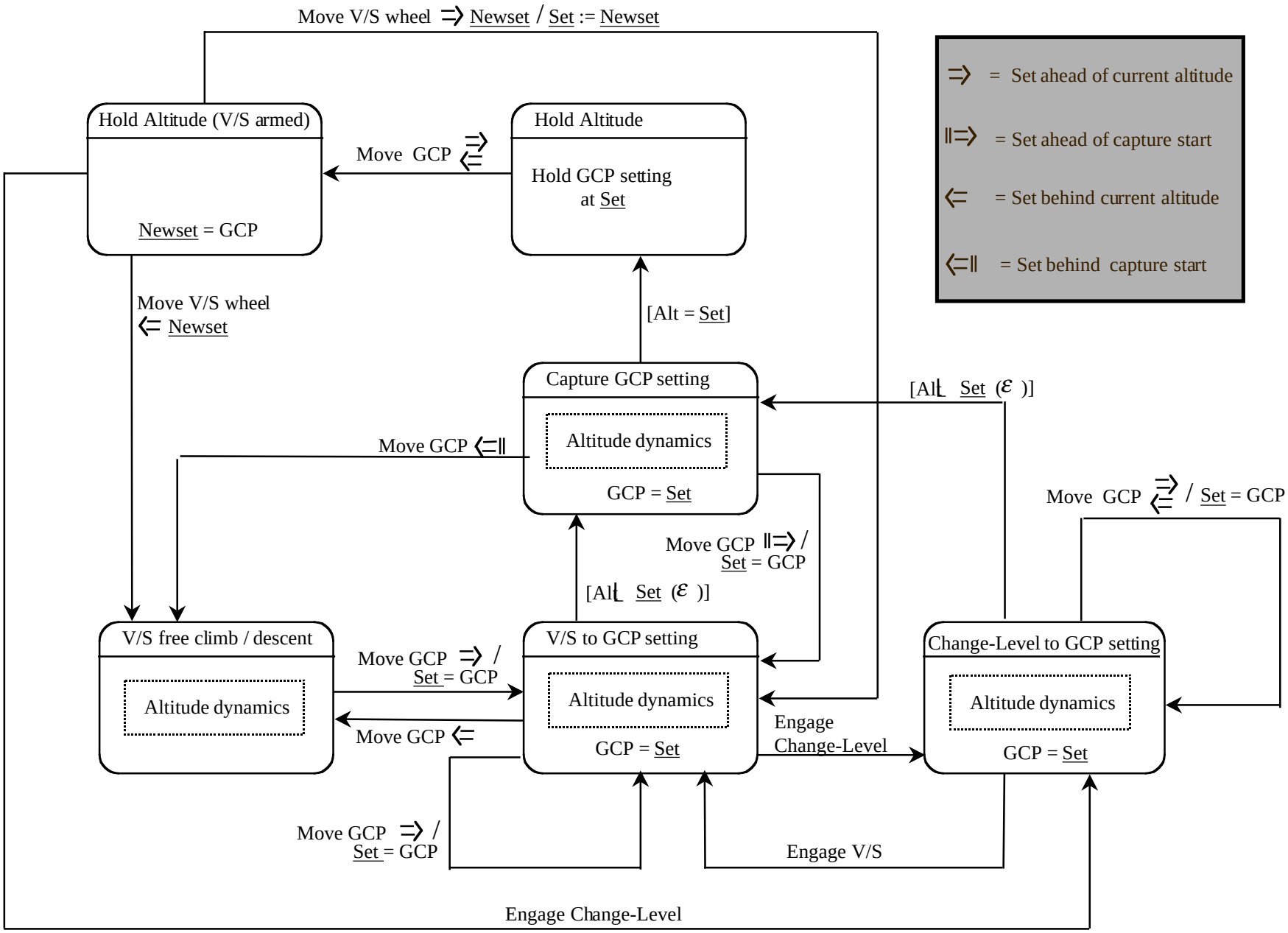


Significant improvement in prediction of the behavior of the automation.

Vertical Mode Control Model According to Training Manual



Vertical Mode Control Model -- Actual



Crew Activity Tracking System (CATS)

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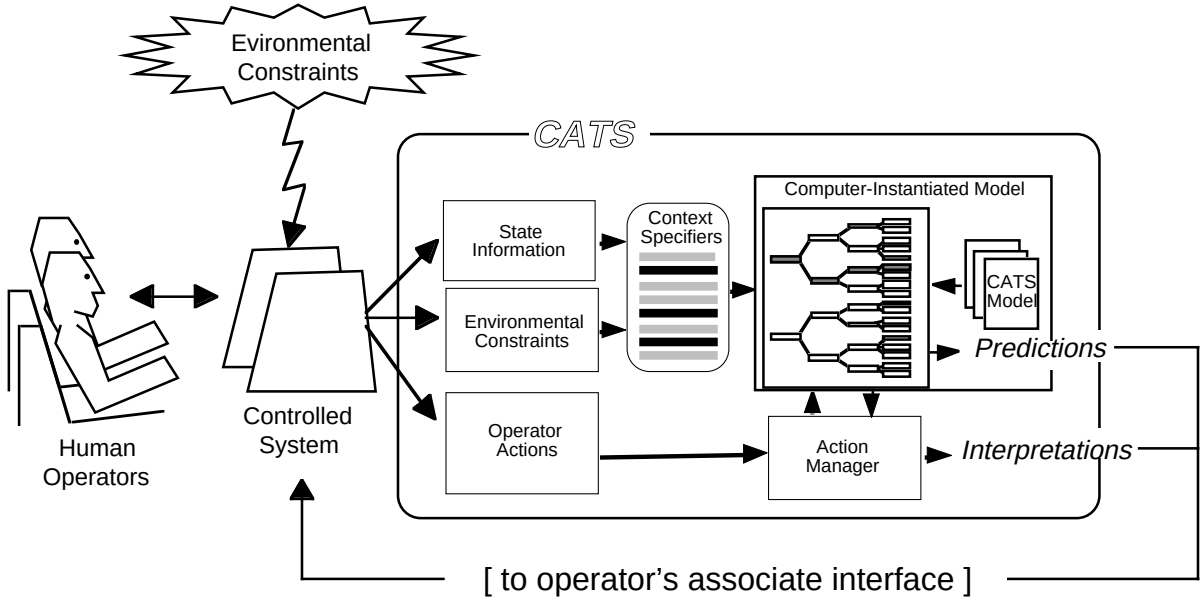
Computer system that uses a model of correct task performance to predict operator activities and interpret operator actions



Provides context-dependent knowledge about the operator's task that can support tutors, aids, and displays to enhance safety

Enables visualization and analysis of operator-automation interaction

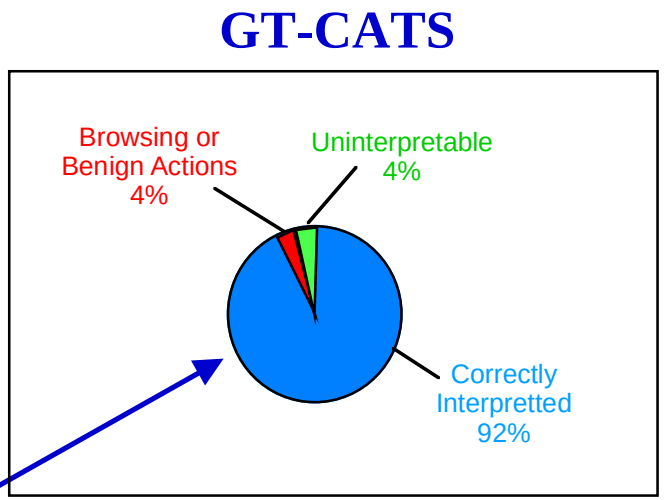
Operator Function Model Family Shows Promise as Recognizing Human Error

Operator Function Model:
Cognitive Task Analysis Methodology together with a visual form

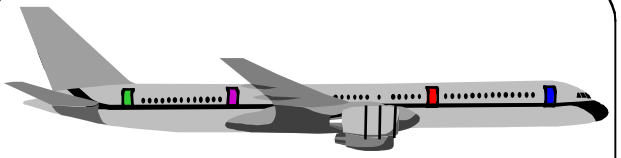
OFMspert:
A 'Living' Task Analysis to undertake intent inferencing

GT-CATS (crew activity tracking):
Variation of OFMspert for intent inferencing in B-757

Enhanced OFM and OFMspert:
Fault Tolerance for Altitude Deviations & Controlled Flight into Terrain (CFIT)



Intelligent Tutoring Systems



The aircraft has four primary access doors:

1. Forward Door
2. Cabin Door
3. Wing Aft Door
4. Aft Door

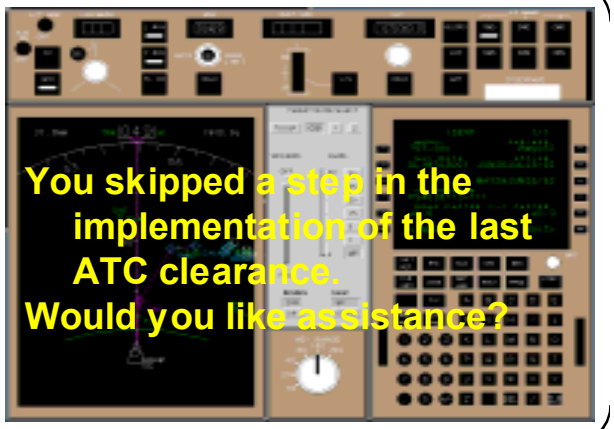
CBT for Declarative Training

(ill-suited)

1. Enter the origin airport in 1L.
2. Enter the destination on 1R.
3. Enter the assigned runway in 3L.
4. Enter …

CBT for Procedural Training

(lockstep)



Intelligent Tutoring Systems

Project Assessment

	3Q98	4Q98	1Q99	Remarks
Project Overall Assessment	G	G	G	**FY99 L1 Milestone is on track**
Technical Performance	G	G	G	
Cost	G	G	G	
Schedule	G	G	Y	**Sub-Element 2.2 staff turnover**

Guidance:

Assessment & L2 Judgement Performance

Cost	*-5% Yellow*
	-15% Red
Schedule	*-1Q Yellow*
	-2Q Red

FUTURE DIRECTIONS

- **Work closely with industry/university partners to ensure**
  - **Innovation**
  - **Excellence**
  - **Impact**

- **Use industry and FAA interest to prioritize projects**

- **Communicate research results**
  - **Technical Reports**
  - **Electronic Media and Multimedia**
  - **Conferences and Workshops**

POTENTIAL ELEMENT CHANGES

FY00++ Significant Funding Uncertainties
==> Extensive descoping and replanning efforts in FY98/99

All program elements are necessary for an adequate human-automation integration research program. Any descoping will damage the effectiveness of the whole program and will compromise NASA's leadership in this area. The proposed demonstration project is the best of a set of weak options.

Possible Criteria for Descoping

- **Future systems design impact > current systems fixes**
- **Aero-space transfer potential > aviation-specific technologies**
- **Synergy with Information Systems > stand-alone human factors work**
- **Capacity and safety benefits > capacity or safety benefits**
- **Design impacts > impacts on training or procedures alone**
- **System-wide impacts > point technologies or single-problem fixes**

Implications

- **One or two demonstration projects**
- **Methodological emphasis (theory, models, simulation)**
- **Significant industry contributions required (possibly JSRA)**
- **Cooperation with FAA**

Summary

- 1.1 State Awareness & Prediction
  - Large-scale analysis of distributed human-automation systems
- 1.2 Displays and Procedures
  - Human-centered design methods for displays and procedures
- 1.3 Human-Automation Theory
  - Formal design synthesis
  - Rigorous safety/liveness properties
- 2.1 Supervisory Control Behavior
  - Predictive task analysis
  - Decision making and action selection
- 2.2 Prototyping for Evaluation
  - Methods for distributed simulation

→ Integration and Safety of Air-Ground Systems [Capacity]

→ Training for Automation [AvSP: Training]

→ Concurrent Design of Displays and Procedures [AvSP: Syn. Vis. Displays]

→ Distributed System Safety Properties [Capacity]

→ Design Safety Assurance [AvSP]

→ Error-Tolerant Systems [AvSP]

→ Distributed Simulation of Air-Ground Integration Concepts [Capacity]

Back-up Charts

Technology Transfer
Publications and Presentations
(N ~= 50)

Control Theory and Computational Sciences: Journals, technical reports, and book chapters

- AIAA Journal of Guidance, Control, and Dynamics
- Annals of Mathematics and Artificial Intelligence
- Hybrid Systems: Computation and Control (book chapter)
- IEEE Transactions on Automatic Control
- IEEE Transactions on Control Systems Technology
- IEEE Transactions on Robotics and Automation
- International Journal of Control
- International Journal of Intelligent Control and Systems
- Journal of Dynamic Systems, Measurement, and Control
- Operators, Systems and Linear Algebra (book chapter)
- Systems and Control Letters
- Transactions on Automatic Control
- Automatica, Special Issue on Hybrid Systems
- Discrete Event Dynamic Systems, Special Issue on Hybrid Systems

Technology Transfer
Publications and Presentations

Control Theory and Computational Sciences: <u>Conferences, symposia, and workshops</u>

- **American Control Conference**
- **Artificial Intelligence, Robotics, and Human Activity**
- **Control Problems in Robotics and Automation**
- **Design, Specification, and Verification of Interactive Systems**
- **Hybrid and Real-Time Systems**
- **Hybrid Systems Workshop**
- **IEEE Conference on Decision and Control**
- **Joint Conference on Artificial Intelligence**
- **Mathematical Theory of Networks and Systems**
- **National Conference on Artificial Intelligence**

Technology Transfer
Publications and Presentations

- **Human Factors and Psychology: Journals, technical reports, and book chapters**

- **Attention (book chapter)**
- **Cognitive Engineering in the Aviation Domain (book chapter)**
- **Handbook of System Design and Management (book chapter)**
- **IEEE Transactions on Systems, Man, and Cybernetics**
- **International Journal of Aviation Psychology**
- **Journal of Experimental Psychology: Human Perception and Performance**
- **NASA TMs and CRs**

Technology Transfer
Publications and Presentations

- **Human Factors and Psychology: <u>Conferences, symposia, and workshops</u>**

- **Cognitive Science Society**
- **Engineering for Human-Computer Interaction**
- **Human Interaction with Complex Systems**
- **Human Factors and Ergonomics Society**
- **Human-Computer Interaction in Aeronautics**
- **IEEE Conference on Systems, Man, and Cybernetics**
- **International Air Transport Association Human Factors 98**
- **Psychonomics Society**
- **Symposium on Aviation Psychology**